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ADVANCES IN CANOPY MANAGEMENT PRACTICES IN COTTON FOR MAXIMIZING COTTON YIELD: A REVIEW

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ABSTRACT

Cotton productivity is strongly influenced by the structure and management of the plant canopy, which regulates essential factors such as light interception, air circulation, and microclimate conditions. Effective canopy management practices aim to optimize these factors to enhance boll development, increase yield, and improve fiber characteristics. Among the various strategies, manual pruning of monopodial branches, detopping of terminal shoots and foliar application of growth regulators like mepiquat chloride have gained prominence for their ability to shape plant architecture and promote resource-use efficiency.

Monopodia removal encourages the plant to allocate more energy to fruiting branches, leading to increased flowering and boll production. This practice also improves air flow and sunlight penetration within the canopy, reducing disease risks and creating a favorable environment for photosynthesis. Detopping controls excessive vertical growth by removing the growing shoot apex, helping synchronize boll maturation and facilitating timely harvest. It contributes to a compact canopy that supports better fruit retention and fiber quality. The growth regulator like mepiquat chloride limits excessive vegetative growth by inhibiting gibberellin biosynthesis. Its judicious application during key growth stages produces a more balanced canopy with improved yield potential and stress tolerance. Combining these cultural and chemical management practices under high-density planting or water-limited conditions enhances cotton's productive efficiency.

Overall, integrated canopy management is a sustainable approach that improves the physiological balance, yield performance, and fiber characteristics of cotton crops. Continued research to refine timings, dosages, and cultivar-specific recommendations will further empower growers to optimize canopy management for enhanced profitability and crop resilience.

Key words : Canopy management, Cotton, Detopping, Monopodia cutting, Mepiquat chloride.

Introduction

Cotton (*Gossypium* spp.) is a crucial commercial crop globally and especially in India, where it plays a significant role in the economy, agriculture and rural livelihoods. Accounting for approximately 25% of the world's natural fiber production, cotton remains indispensable for the textile industry and employment generation (Pawar *et al*., 2024). India ranks second globally in cotton production but faces challenges such as low productivity due to poor soil health, erratic rainfall, and other biotic and abiotic stresses (Lipane *et al*., 2024). Thus, optimizing agronomic practices like canopy management is essential to enhance cotton yield and quality.

Beyond its economic value, cotton cultivation supports millions of smallholder farmers and contributes substantially to export earnings in developing countries. However, yield stagnation in major cotton-growing regions highlights the need for improved crop management strategies that enhance resource-use efficiency under changing climatic conditions. Climate variability, nutrient imbalances, and increasing pest pressure further exacerbate yield gaps, making canopy-oriented agronomic interventions increasingly relevant for sustaining cotton productivity (Constable and Bange, 2015; Ritchie *et al*., 2004).

The canopy structure of cotton significantly affects physiological processes such as light interception, photosynthesis, and microclimate regulation, which in turn impact biomass accumulation, fruiting, and fiber quality (Jiang *et al*., 2018; Gao *et al*., 2024). Excessive vegetative growth often causes resource diversion away from reproductive parts, resulting in flower and boll shedding, delayed maturation, and yield loss (Pawar *et al*., 2024). Effective canopy management techniques including pruning of monopodia, detopping, use of plant growth regulators (e.g., mepiquat chloride), mulching, and optimized row spacing help regulate plant architecture, improve light distribution, and promote boll retention (Balasubramanian *et al*., 1992; Pawar *et al*., 2024; Lipane *et al*., 2024; Gao *et al*., 2024).

Physiologically, a balanced canopy ensures an optimal leaf area index that maximizes photosynthetically active radiation interception while minimizing self-shading. Improved canopy openness enhances carbon assimilation efficiency and supports sustained assimilate translocation to developing bolls. Moreover, favorable canopy microclimates help stabilize temperature and humidity around fruiting zones, which is critical for boll development and fiber elongation, particularly during peak reproductive stages (Reddy *et al*., 1996; Bednarz *et al*., 2000).

High-density planting systems combined with canopy management have shown promising results in increasing plant density without compromising yield, improving microclimate conditions, and enhancing water use efficiency in cotton cultivation (Lipane *et al*., 2024; Gao *et al*., 2024). Technological advancements such as 3D imaging and remote sensing enable precise quantification of canopy traits, allowing better monitoring and breeding for desirable canopy architecture (Jiang *et al*., 2018). Despite these developments, integration of physiological insights with tailored canopy management practices for diverse genotypes and environments remains an ongoing research focus.

The use of precision agriculture tools allows real-time assessment of canopy vigor, plant height, and leaf area distribution, enabling site-specific management decisions. Such approaches support optimized application of growth regulators and irrigation scheduling, reducing input costs while improving productivity. Nonetheless, the response of cotton canopy traits to management practices varies with genotype, environment, and cropping system, underscoring the need for location-specific recommendations and long-term field validation (Gwathmey and Clement, 2010; Constable, 2020).

This review aims to comprehensively synthesize the current knowledge on cotton canopy management. It addresses physiological mechanisms, evaluates agronomic interventions, and examines technological innovations to optimize canopy structure and improve cotton productivity sustainably. Key gaps in research and future directions will also be highlighted.

Integrated Canopy Management practices

Monopodia cutting

In cotton, removal of monopodia is the process of pruning unproductive vegetative branches (monopodia) to enhance growth and yield. This process involves cutting off the monopodia at around 40-45 days (Bharatiya Kisan Sangh, 2021 and Cotton Association of India, 2024)) after sowing redirect the plant's energy toward fruiting branches (sympodial). This management practice aids in regulating the plant's growth, allowing better light penetration, better boll retention and air circulation, which together contribute to increased productivity and superior crop quality.

Purpose : Monopodia removal facilitates a balance between vegetative and reproductive growth by stimulating the development of lateral fruiting branches (sympodia) (Mundare *et al*., 2025). Improved light penetration and enhanced air circulation within the crop canopy increases boll retention and reduce fruit drop (Pawar *et al*., 2024). Furthermore, the creation of a favourable microclimate supports improved yield potential and overall crop productivity.

Criteria and Procedure

- **Timing:** The operation is generally carried out 40-45 days after sowing (DAS), once the plants are well established but before excessive monopodial growth begins (Cotton Association of India, news, 2024).
- **Method:** Cut off the monopodia 2-3 cm away from the main stem using sharp scissors or garden secateurs to avoid injuring the main stem.
- Usually, 2-4 monopodial branches per plant are eliminated.
- Post-pruning, regrowth at each node should be monitored and removed when necessary to sustain the effectiveness of the practice.
- **Tools :** Manual cutting is most commonly done using garden secateurs or sharp scissors. Mechanical methods are also possible on large-scale farming systems.

Benefits : Removal of monopodial branches has been shown to improve cotton productivity by increasing the number of sympodial branches and bolls per plant. This practice also enhances average boll weight and overall seed cotton yield by improving canopy structure and optimizing the partitioning of photosynthates and other growth resources (Reddy *et al.*, 2017).

Detopping : Detopping, also referred to as nipping or pinching, is a crucial practice in cotton cultivation for maximizing seed cotton yield. The precise timing of detopping is of paramount importance for its success. Ideally, detopping is carried out when cotton plants are around 90 to 100 days after sowing (DAS) and are initiating boll formation, particularly in rainfed areas (Lipane *et al*., 2024). This timing ensures a harmonious balance between vegetative growth and the critical phase of boll development. Detopping entails the deliberate removal of the terminal or apical meristem of the cotton plant's primary stem. This is typically achieved by gently cutting or pinching the top portion of the main stem. The objective of detopping is to redirect the plant's energy and resources away from vertical growth, ultimately encouraging lateral development (Pawar *et al*., 2024). This redirection enhances the emergence of additional fruiting branches and promotes increased boll production.

A key consequence of detopping is its direct effect on plant height reduction. The removal of the apical meristem restricts further elongation of the main stem, thereby limiting vertical growth. Consequently, assimilates and growth energy are redirected toward the development of lateral branches, resulting in a more compact and bushy plant architecture. When properly implemented, detopping plays an important role in enhancing boll-bearing capacity and supporting improved yield potential.

The following considerations are essential for successful detopping:

- **Tools:** The use of well-cleaned and sharpened pruning shears, secateurs, or handheld clippers is essential to achieve a smooth and accurate cut, thereby reducing mechanical injury to the plant (CICR, 2023).
- **Sympodial Branches:** Ensure the cotton plant has attained a certain level of fruiting, typically 12-15 sympodial branches (Wang *et al*., 2014).
- **Height:** This practice is most effective when plants attain the optimal height range of 1.0-1.3m (4-5 ft)**,** ensuring a balance between vegetative growth and reproductive development (Bharatiya Kisan Sangh, 2021).
- **Method:** Detopping is executed manually by making a clean cut or pinch approximately 10-15 cm (or) half a foot from the terminal portion of the main stem, targeting the brown stem section only. Pinching of the soft green terminal portion should be avoided, as it may lead to excessive apical branching and adversely affect boll development (Cotton Association of India, 2024).
- **Care:** Special care should be exercised to ensure a precise cut while minimizing the risk of damage to bark, lateral branches, and existing bolls, thereby ensuring the effectiveness of the operation (Anonymous, 2024a).
- **Following detopping:** Diligent observation and monitoring are essential for achieving the desired outcomes. Successful detopping encourages the development of lateral branches and an increased number of fruiting positions, which ultimately contributes to a higher boll load per plant (Anonymous, 2024b; Anonymous, 2022).

Spraying of mepiquat chloride

To curtail excessive vegetative growth and improved retention of early-formed bolls under high-density planting systems (HDPS), plant growth regulators such as mepiquat chloride are commonly applied. The regulator is typically sprayed two-three times, with the initial application scheduled at the onset of square formation, corresponding to 40-45 days after sowing. The schedule for PGRs in rainfed cotton is presented in Table 1.

Table 1 : Schedule for PGRs in rainfed cotton.

Canopy Management schedule	Dosage of commercial formulation (Mepiquat Chloride 5% AS)
I Spray (40-45-day crop or square initiation or crop is 40-45 cm tall)	1.0 ml/litre of water
II Spray (15-20 days after first spray) or 55 to 65 days crop	1.2 ml/litre of water
III spray (need based in case of excessive growth due to rains)	1.2ml/litre of water

Source: Prasad *et al*. (2023)

The application frequency and optimal dosage of mepiquat chloride have been extensively evaluated in recent years. Application rates between 1-1.2 ml/lit, aligned with squaring to early bloom stages, regulate gibberellin biosynthesis effectively, limiting excessive vegetative growth without compromising yield. Previous studies have elucidated the physiological and molecular basis of this response, demonstrating that mepiquat

Plate 1 : Operation of monopodia removal.

Plate 2 : Monopodia after cutting.

Plate 3 : Cotton crop after removal of monopodia.

chloride reduces gibberellin activity, resulting in a more compact canopy, improved fruit retention and enhanced tolerance to abiotic stress conditions Tung *et al*. (2020) and Wu *et al*. (2023). Research by Wang *et al*. (2014) and others demonstrated how crop geometry modifications combined with mepiquat chloride application optimize plant spacing and canopy structure for uniform light interception, ultimately contributing to more uniform growth and increased productivity.

The need and number of canopy management spray is dependent upon-

- The necessity and number of canopy management sprays are influence by several factors, including soil type, growth pattern of variety/hybrid, prevailing/anticipated weather condition, retention of first position bolls, spacing/plant population
- IInd and IIIrd sprays are recommended when the average length of the Top five internodes (ALT5) is more than 4 cm (ALT5 is basically height node ratio (HNR) of the top five nodes) (CICR, 2023) serves as an indicator of excessive vegetative growth.
- Prior to the application of any spray of PGRs, ensure sufficient moisture in soil with no forecast of dry spell in next 10 days.
- Observation for ALT5 should be conducted after 15 days after first or second spray. If ALT5 is less than 4 cm, repeat the observation after every week. When ALT5 is more than 4, spray PGR (CICR, 2023).
- Accurate identification and counting of nodes are critical, as errors in node assessment can lead to incorrect ALT5 estimation.
- Undertake PGR spray an 8-hour rain-free period is required for optimum performance of mepiquat chloride (Thomas *et al*., 2007).

Molecular structure of mepiquat chloride

Mechanism of mepiquat chloride after spraying on cotton

The plant growth regulator mepiquat chloride (MC), N, N dimethyl piperidinium chloride, is a water-soluble organic molecule favorably absorbed by the leaves and young green stems and then translocated throughout the whole plant systemically through plant xylem and phloem (Thomas *et al*., 2007), and has been most successful and worldwide used to control plant canopy size in cotton production (Roselem *et al*., 2013). After entering the tissues, mepiquat chloride acts as an anti gibberellin by

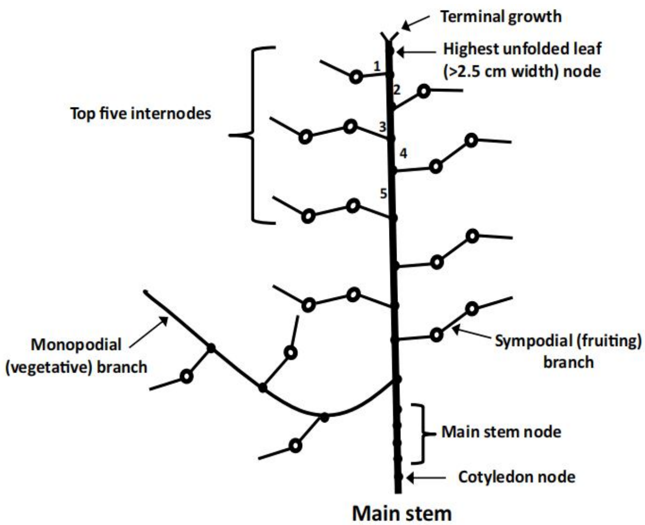

Plate 4 : Cotton canopy structure (Prasad *et al.*, 2023).

Plate 5 : Tool-secateurs used for detopping.

Plate 6 : Cotton plant height @ 100 DAS.

Plate 7 : Pinch the top 10-15 cm or half foot in brown colour main stem.

Plate 8 : Detopping view of cotton plant.

inhibiting gibberellin biosynthesis (Rademacher, 2000 and Srivastava., 2002), the hormone group responsible for promoting stem elongation and cell expansion in cotton (Singh *et al.*, 2023). Because gibberellin production is reduced, cells in internodes and petioles divide normally but elongate less, so plant height and internode length decrease while stems become shorter and more compact (Sibert and Steward, 2006; Ren *et al.*, 2013, Singh *et al.*, 2023 & Albers and Schnakenberg, 2025). Reduced cell elongation in expanding leaves also lowers individual leaf size and total leaf area index, which produces a smaller, more open canopy (Singh *et al.*, 2023; Albers and Schnakenberg, 2025). By limiting excessive vegetative growth, more assimilates and nutrients are partitioned toward reproductive organs (squares, flowers and bolls), resulting in improved fruit retention and more synchronous boll set (Patel *et al.*, 2021). The more open canopy improves penetration of light (Kiran *et al.*, 2010), air and foliar sprays into the middle and lower canopy, which can reduce boll rot (Fang *et al.*, 2019) and make pest and disease management as well as mechanical harvesting more efficient (Zhao *et al.*, 2017). Physiologically, mepiquat chloride can increase leaf chlorophyll concentration, giving leaves a darker green appearance and sometimes improving photosynthetic efficiency per unit leaf area Singh *et al.* (2023). Overall, after spraying on a vigorously growing cotton crop, mepiquat chloride shifts the hormonal balance to restrict vegetative

Plate 9 : After detopping 110 DAS.

Plate 10 : Cotton after 25 days detopping showing more no. of bolls and increase sympodial length.

Plate 11 : Mepiquat chloride.

Plate 13 : Spraying of MC 40-45 DAS.

Plate 12 : Preparing MC solution (1 ml/lit).

Plate 14 : Difference in No. of boll between control & canopy management in cotton.

overgrowth, create a compact canopy, enhance boll retention and earliness, and ultimately support better lint yield and fiber quality when used under appropriate growth and stress conditions (Shi *et al*., 2022 and Singh *et al*., 2023).

Future perspective

Integrated cotton canopy management will benefit from forthcoming precision agriculture technologies and cultivar-specific protocols, enabling growers to optimize timing and dosage of practices such as detopping and mepiquat chloride application. Future research should emphasize tailoring these interventions to climate variability and improving decision-support systems to achieve higher productivity, better fiber quality and

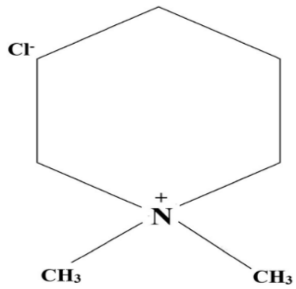

Fig. 1 : Molecular structure of mepiquat chloride containing a benzene ring in which a carbon atom bonded with nitrogen at one end and further linked with two methyl groups and free chloride ion at the other carbon end (Rademacher, 2015).

enhanced sustainability of cotton production systems.

Emerging precision agriculture tools, including remote sensing platforms, unmanned aerial vehicles (UAVs) and proximal sensors, are expected to play a pivotal role in real-time monitoring of canopy traits such as plant height, leaf area index, and canopy vigor. These technologies can facilitate early detection of excessive vegetative growth or stress conditions, enabling timely and site-specific canopy interventions. Integration of sensor-derived data with crop growth models and weather-based advisories will further improve the accuracy of recommendations related to detopping and plant growth regulator applications under variable climatic scenarios (Jiang *et al*., 2018; Gao *et al*., 2024).

In addition, the development of cultivar-specific canopy management protocols will be increasingly important due to genetic variability in growth habit, branching pattern and responsiveness to agronomic interventions among cotton genotypes. Future research should focus on linking physiological traits with management responses to design genotype-by-environment-specific strategies. Strengthening decision-support systems through the integration of physiological insights, precision technologies, and farmer-friendly digital platforms will enhance adoption and contribute to improved productivity, superior fiber quality, and long-term sustainability of cotton production systems (Constable and Bange, 2015; Gwathmey and Clement, 2010).

Conclusion and Future Perspectives

Integrated canopy management approaches-including removal of monopodia, detopping, and spraying of mepiquat chloride, play a significant role in improving cotton yield and fiber quality by regulating canopy structure and physiological balance. Combining these strategies with precise scheduling and cultivar-specific adjustments enhances boll retention, resource use efficiency and resilience under variable environmental conditions. Adoption of such integrated strategies can help cotton producers achieve greater productivity and long-term sustainability while addressing agronomic and climatic challenges.

From a physiological perspective, integrated canopy management optimizes source–sink relationships by limiting excessive vegetative growth and improving assimilate partitioning toward reproductive organs. Removal of monopodia reduces competition among vegetative sinks, while detopping restricts apical dominance, resulting in synchronized flowering and improved boll retention. Application of mepiquat chloride further complements these practices by suppressing internode elongation and moderating leaf area development, thereby promoting a compact and efficient canopy architecture (Zhao and Oosterhuis, 2000; Gwathmey and Clement, 2010).

The combined implementation of mechanical and chemical canopy management practices also improves microclimatic conditions within the crop canopy by enhancing light penetration and air circulation. These favorable conditions support sustained photosynthetic activity and reduce the incidence of biotic stresses, particularly under high-density planting or irrigated systems. Furthermore, improved canopy balance enhances water and nutrient-use efficiency, which is critical for maintaining yield stability under moisture-limited or heat-stress environments (Reddy *et al*., 1996; Bednarz *et al*., 2000).

Integrating canopy management strategies with precise timing and cultivar-specific recommendations allows growers to respond effectively to genotype-specific growth patterns and environmental variability. Such tailored approaches improve the consistency of fiber quality attributes, including length, strength and micronaire, while reducing input costs and environmental impacts. Consequently, adoption of integrated canopy management represents a viable pathway toward resilient, high-productivity, and sustainable cotton production systems in the face of increasing climatic and agronomic challenges (Constable and Bange, 2015; Ritchie *et al*., 2004).

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